

Production of four jets in LR model[†]

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Abstract

We consider the reaction $e^-e^- \rightarrow q q \bar{q} \bar{q}$ as a test of lepton number non-conservation in the framework of the left-right-symmetric electroweak model. The main contributions to this process are due to Majorana neutrino exchange in t -channel and doubly charged Higgs (Δ^{--}) exchange in s -channel with a pair of right-handed weak bosons (W_R) as intermediate state. We show that in a linear e^-e^- collider with the collision energy of 1 TeV (1.5 TeV) the cross section of this process is 0.01 fb (1 fb), and it will, for the anticipated luminosity of $10^{35} \text{ cm}^{-2}\text{s}^{-1}$, be detectable below the W_R threshold. We study the sensitivity of the reaction on the masses of the heavy neutrino, W_R and Δ^{--} .

1. Introduction

The electroweak model with the left-right (LR) gauge symmetry $SU(3)_c \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}$, proposed in [1], is one of the most popular extensions of the Standard Model (SM). It gives a better understanding of parity violation than the SM and it maintains the lepton-quark symmetry in weak interactions. Parity is in it broken spontaneously, and embedding of the model into the SO(10) grand unified scheme [2] can be implemented consistently when the scale of the discrete LR-symmetry breaking is more than 1 TeV or so.

Perhaps the most important property of the LR-model is its ability to provide, in terms of the seesaw mechanism [3], a simple and natural explanation to the smallness of the masses of the ordinary neutrinos. The recent observation by the SuperKamiokande experiment of the atmospheric neutrino oscillations [4] confirmed that at least some of the neutrino species do have a mass, giving an additional argument in favour of the LR-symmetric model.

An essential ingredient of the LR-model are the triplet Higgses. Their interactions with fermions break the lepton number by two units. In the literature different observable lepton number violating processes, including doubly charged Higgs production [5], vector-boson pair and

triple production for electron-positron and electro-electron colliders [6, 7], have been investigated.

In the present talk we will consider the lepton-number violating process

$$e^-e^- \rightarrow q q \bar{q} \bar{q} \quad (1)$$

with various quark flavour combinations. One would expect to obtain indirect evidence of the LR-model via this process well below the threshold of W_R^\pm . The details of this study may be found in [9].

2. Numerical Results

By means of CompHEP [10] we have derived the squared matrix elements for $e^-e^- \rightarrow b b \bar{t} \bar{t}$ and computed the ensuing cross sections at the collision energies $\sqrt{s} = 1 \text{ TeV}$ and $\sqrt{s} = 1.5 \text{ TeV}$. The results depend on a number of unknown parameters of the LR-model, the most important ones being the masses of the right-handed boson W_R and doubly charged Higgs-Majoron Δ^{--} . We consider theory without $W_L - W_R$ mixing and neglect small effects of the seesaw mixing. We restrict ourselves to the manifestly left-right symmetric case, implying that the left and right-handed interactions have the same coupling strength, i.e. $g_L = g_R$, and that the Kobayashi-Maskawa mixings of the right-handed charged currents are exactly the same as those of the left-handed ones, in particular $V_{tb}^R = V_{tb}^L \equiv V_{tb}$.

In Fig. 1 we show the energy dependence of the total cross section of the process $e^-e^- \rightarrow b b \bar{t} \bar{t}$ for various values of masses of the triplet Higgs Δ^{--} and the right-handed neutrino ν_2 . In all the

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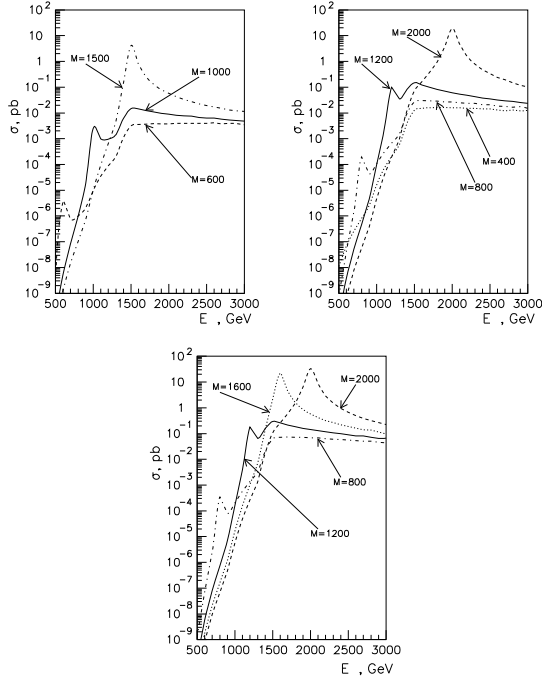


Figure 1. Energy dependence of the full cross section for the process $e^-e^- \rightarrow b b \bar{t} \bar{t}$ for different values of Δ^{--} mass ($M \equiv M_{\Delta^{--}}$) and right-handed neutrino masses: $m_{\nu_2} = 1$ TeV (left upper picture), $m_{\nu_2} = 1.5$ TeV (right upper picture), $m_{\nu_2} = 2$ TeV (lower picture), (see comments in the text).

cases the right-handed boson mass is taken to be $M_{W_R} = 700$ GeV.

In Fig. 2 we present the sensitivity contours for $\sqrt{s} = 1.5$ TeV with the masses of the right-handed neutrinos 1.5 TeV. The achievable limit for M_{W_R} is now about 1.5 TeV at the triplet Higgs resonance and outside the resonance about 1 TeV, a considerable improvement to the present bound. As the cross section is proportional to the mass of neutrino, the larger m_{ν_2} the more stringent are the ensuing constraints. Following the arguments of [11] we apply the following cuts:

- Each b-jet should have energy more than 10 GeV.
- Each t-jet should have energy more than 190 GeV.
- The opening angle between two detected jets should be greater than 20° .
- The angle between each detected jet and the colliding axis should be greater than 36° .

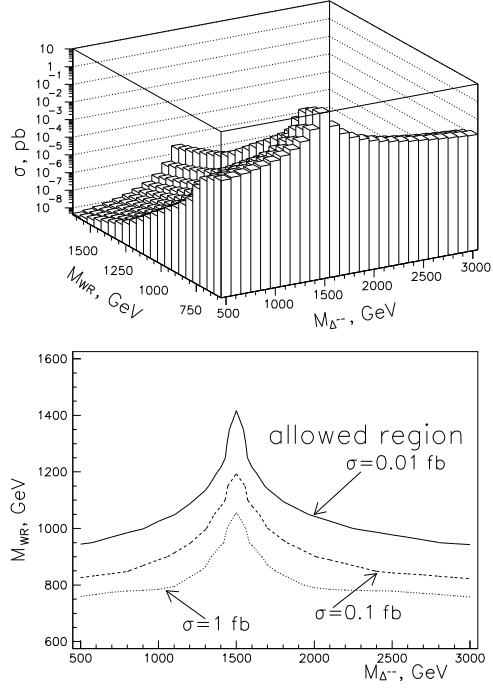


Figure 2. Cross section for the $e^-e^- \rightarrow b b \bar{t} \bar{t}$ and its contourlevels at $\sigma = 0.01$ fb (30 events per year), $\sigma = 0.1$ fb (300 events per year), $\sigma = 1$ fb (3000 events per year) for the energy $E = 1.5$ TeV, and the right-handed neutrino mass $m_{\nu_2} = 1.5$ TeV.

- The total energy of the event should be greater than 400 GeV.

If we impose for the counterparts of the top quarks, the c quarks, in the reaction $e^-e^- \rightarrow s s \bar{c} \bar{c}$ the cut $E_{\bar{c}1,2} > 190$ GeV, which is very effective in diminishing the SM background (see below), the cross sections differ not more than 12 %. Hence, one can immediately write down the following approximative relations between the cross sections of the reactions with no, one and two b -jets in the final state:

$$\sigma(0b) \approx \sigma(1b) \approx 4 \cdot \sigma(2b); \quad (2)$$

This relation may be very useful as a test of the LR-model.

The main SM background of the reaction $e^-e^- \rightarrow b b \bar{t} \bar{t}$ is due to the process $e^-e^- \rightarrow \nu_e \nu_e b b \bar{t} \bar{t}$, which has the same visible particles in the final state. If we impose the cut of 50 GeV on the energies of the final state electrons, the cross section

$\sigma(e^-e^- \rightarrow e^-e^-W^+W^-)$ diminishes by 3 orders of magnitude and yields the background at 1.5 TeV collision energy on the 0.03 fb level. There is a further suppression in the case of the $bb\bar{t}\bar{t}$ due to the fact the intermediate W_L bosons should actually be away from the pole as the invariant mass of its decay products b, \bar{t} should be greater than m_t . This yields altogether 8 orders of magnitude suppression of the background, making it fully harmless.

3. Summary

It is shown that the reaction $e^-e^- \rightarrow q q \bar{q} \bar{q}$ may be observed at NLC for a wide range of reasonable parameter values of the left-right symmetric model and already below the W_R threshold. For the collision energy $\sqrt{s} = 1.5$ TeV and luminosity $10^{35} \text{cm}^{-2} \cdot \text{s}^{-1}$ the lower limit for the mass of the right-handed gauge boson one could reach is $M_{W_R} \gtrsim 1000$ GeV. Near the doubly charged Higgs (Δ^{--}) resonance the lower bound on M_{W_R} may reach, and even exceed, the value of the collision energy. As the lepton number violation and neutrino masses are intimately connected through the Maojara mass terms, the strength of the $e^-e^- \rightarrow q q \bar{q} \bar{q}$ process increases with the growth of the mass of the right-handed neutrino. The "non-diagonal" processes, i.e. the reactions where the $\bar{q}q$ pair or pairs in the final state mix with fermion families, are essentially suppressed, while all the "diagonal" processes have approximately the same probability. Process $e^-e^- \rightarrow bb\bar{t}\bar{t}$ can be identified as b -tagging is possible. For the processes involving only light quarks or containing just one b -jet are approximately related to this cross section by eq. (2).

The SM background can be suppressed to the level 4 orders of magnitude below the process rate if the proper cuts in the phase space are applied, and it can be made even 7 orders of magnitude below the signal level if the full energy of the event can be reconstructed with the accuracy of 50 GeV.

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